

Aeromat 2003
Dayton, Ohio

***Self-Reacting Friction Stir Weld
for Aluminum
Complex Curvature Applications***

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National Aeronautics
and Space Administration

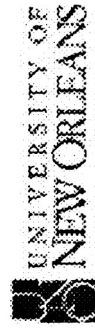
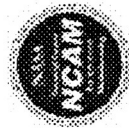
Acknowledgements



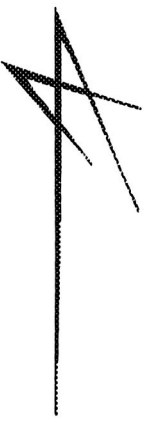
NASA Led Space Launch Initiative / Next Generation Launch Technologies (SLI/NGLT) Friction Stir Welding Complex Curvature Risk Reduction Program

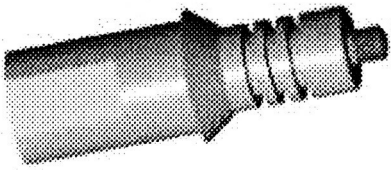
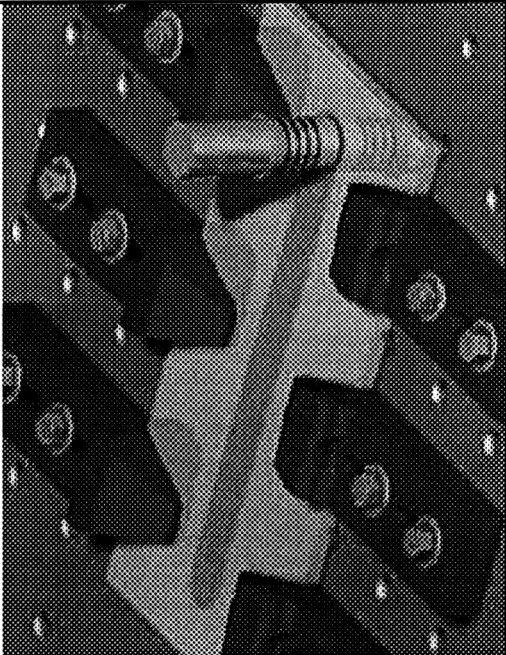
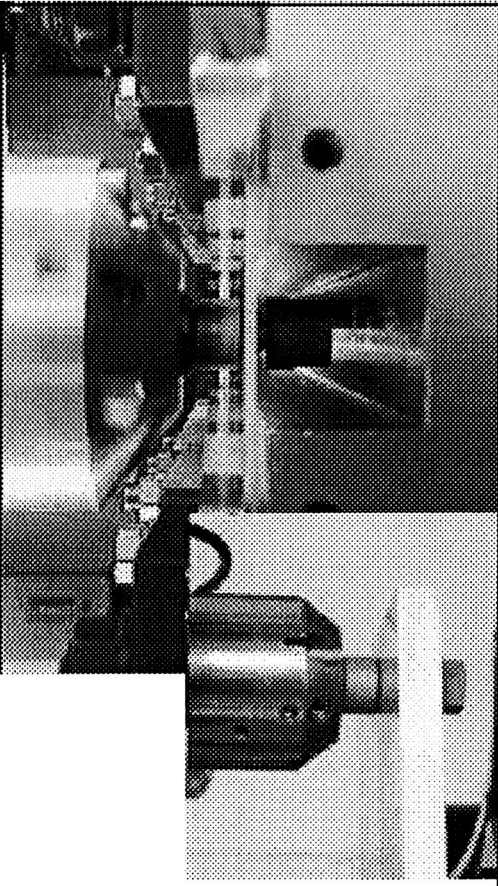
- Funded through the University of New Orleans National Center for Advanced Manufacturing University Research Cooperative Agreement

- Chip Jones - Program Manager, NASA MSFC
- Bruce Brailsford - Director, NCAM University of New Orleans
- Jules Schneider - Program Manager, Lockheed Martin



Conventional vs. Self-Reacting



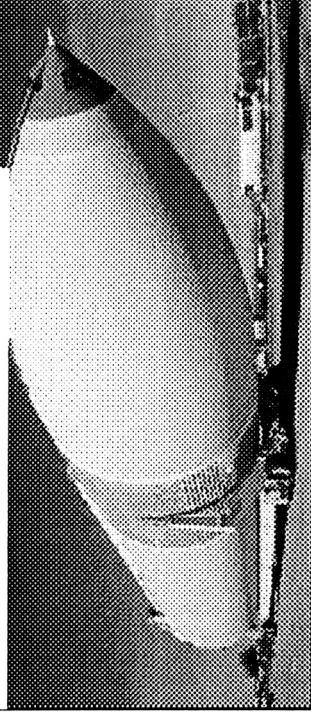
Conventional (FPT and APT) FSW	Self-Reacting (SR-FSW)
• The FSW tool consists of a crown-side shoulder and a pin • The forge load is provided by controlling the position and/or load of the shoulder • Requires a backing anvil with support structure to react the forge load	• The FSW tool consists of two shoulders with a pin that goes through the base material, the bottom shoulder is attached to the pin • The forge load is provided by controlling the relative position and/or load between the two shoulders • Eliminates the backing anvil requirement
 	

Cryogenic Tankage Welding Needs

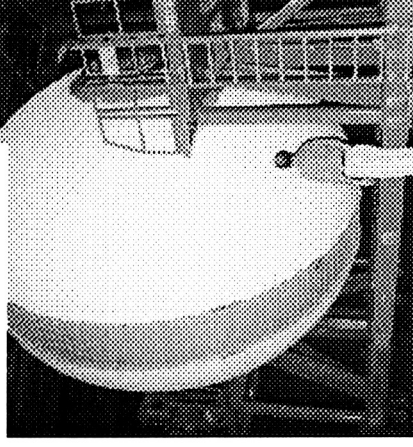
Large Fuel Tanks are comprised of four major weld configurations

- **Longitudinal**
 - In production on ET and Delta II and IV barrels
- **Circumferential**
 - Demonstrated up to 14 ft. dia. since 1998
 - 27.5 ft. dia demonstration planned in late 2003
- **Complex Contour**
 - Gore-to-gore for large domes currently in work
 - Conformal configurations for future launch vehicles
- **Circular**
 - In research and development

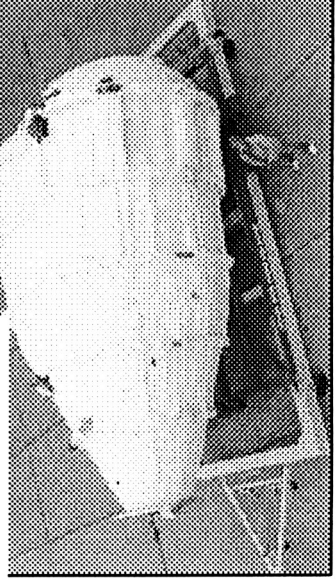
Space Shuttle External Tank (ET)



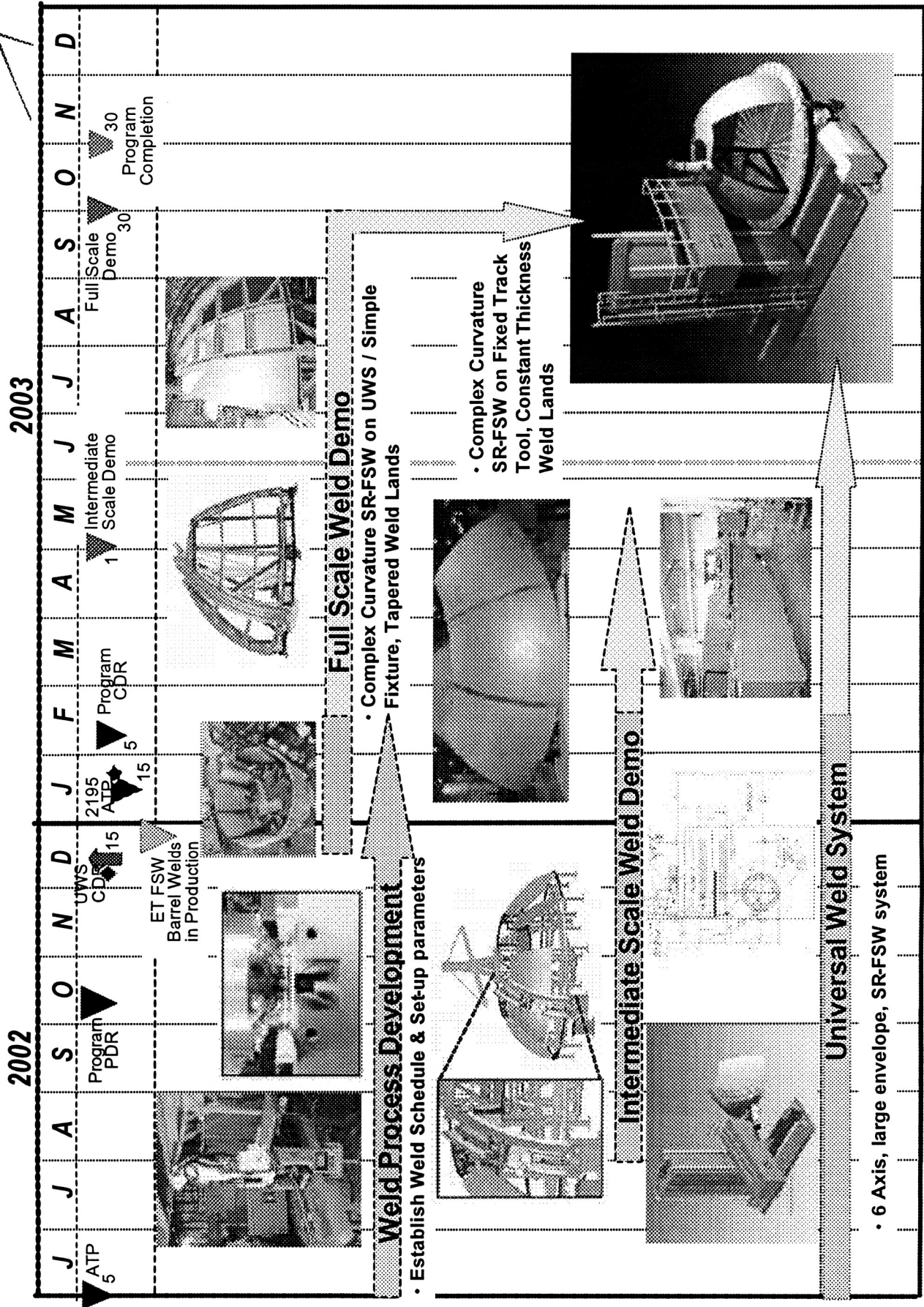
Kistler LAP Tank



X-33 LO2 Tank



NGLT Complex Curvature SR-FSW Risk Reduction Program



Building Block Design-to-Manufacture Approach

Weld Process Development

- MTS Adjustable, Adaptable Pin Tool (AdAPT) Weld Head, Controller and Product Development Fixture (PDF)
- Constant Thickness Al2219-T87 to Al2219-T87 Flat Panels
 - 0.320, 0.360 and 0.385 gage

Weld Process Transfer

- MTS AdAPT Weld Head & Controller on Gore to Gore Weld Tool
- 0.320 gage Al2219-T87 Curved Confidence Panels (24" & 84")

Intermediate Hardware Demonstration

- MTS AdAPT Weld Head & Controller on Gore to Gore Weld Tool
- 0.320 gage Al2219-T87 Quarter Panel Fabrication

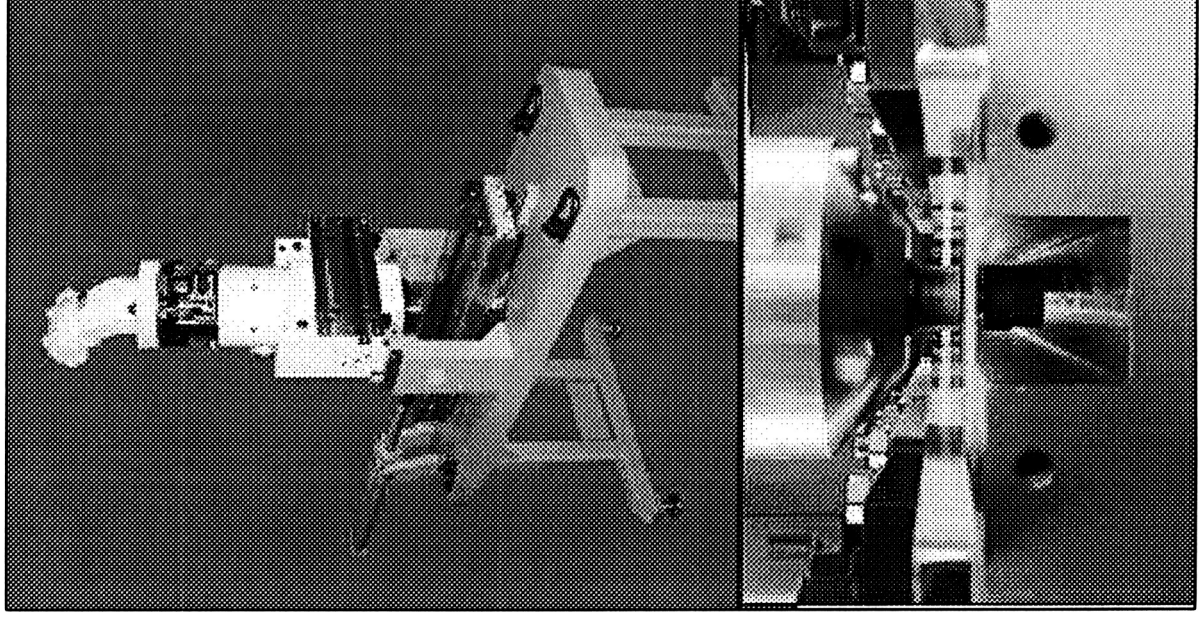
Weld Process Development

Approach

- Utilize a Designed Experiment approach to develop an operating box for welding Al2219
 - 0.320, 0.360 and 0.385 gage
 - Load, travel and rotation speed
 - Visual and radiographic inspection
 - Microstructural analysis
 - Tensile testing at ambient & LN2 temperatures

Success Criteria

- Average room temperature $F_{tu} \sim 48$ ksi
- LN2 enhancement of 1.2
- Visual & Radiographic Inspection



Weld Process Development

Mechanical property goals for 0.320 and 0.400 gage were accomplished over a range of rotation and travel speeds and forging load

RT UTS

Goal: Average of 48 ksi

Actual: Average of 51.6 ksi

LN2 (-320°F) UTS

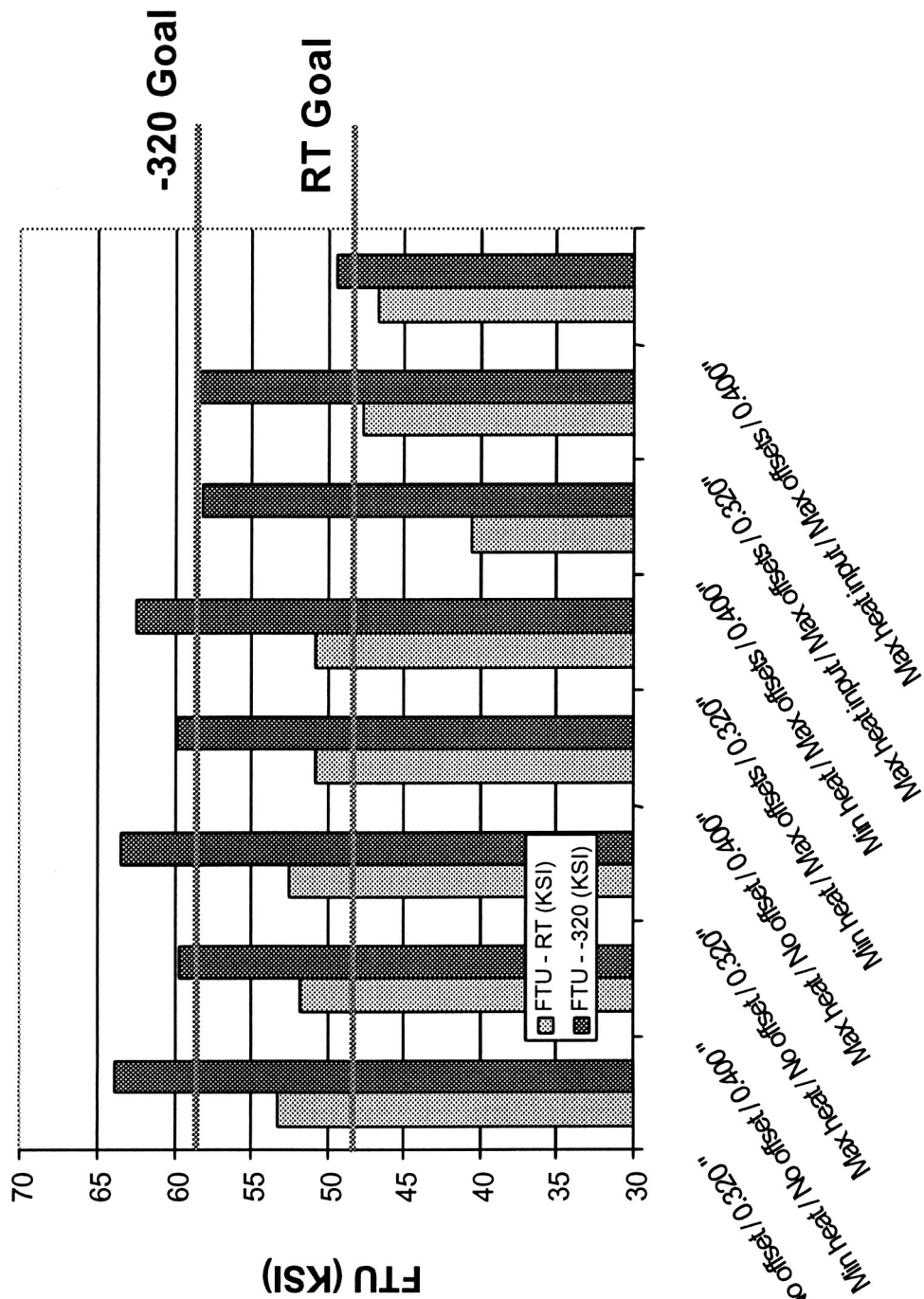
Average 57.6 ksi (1.2 enhancement)

Average of 62.0 ksi

Weld Schedule	Thick. (in.)	Ultimate Strength (ksi)			Yield Strength (ksi)			2 inch Elong. (%)		
		RT	LN2		RT	LN2		RT	LN2	
		Ave	Ave	Ratio	Ave	Ave	Ratio	Ave	Ave	Ratio
Min	0.320	52.5	64.7	1.23	25.5	29.8	1.17	11.6	15.5	1.34
Min	0.400	52.2	60.0	1.15	27.9	25.5	0.91	11.2	15.3	1.36
Nom	0.320	52.6	63.9	1.21	25.1	27.9	1.11	12.9	16.3	1.26
Nom	0.400	52.9	64.7	1.22	26.2	30.5	1.16	13.5	16.0	1.19
Max	0.320	48.8	60.5	1.24	24.3	28.0	1.15	7.7	10.0	1.30
Max	0.400	50.8	58.5	1.15	24.4	27.0	1.10	10.5	10.9	1.04

Weld Process Development

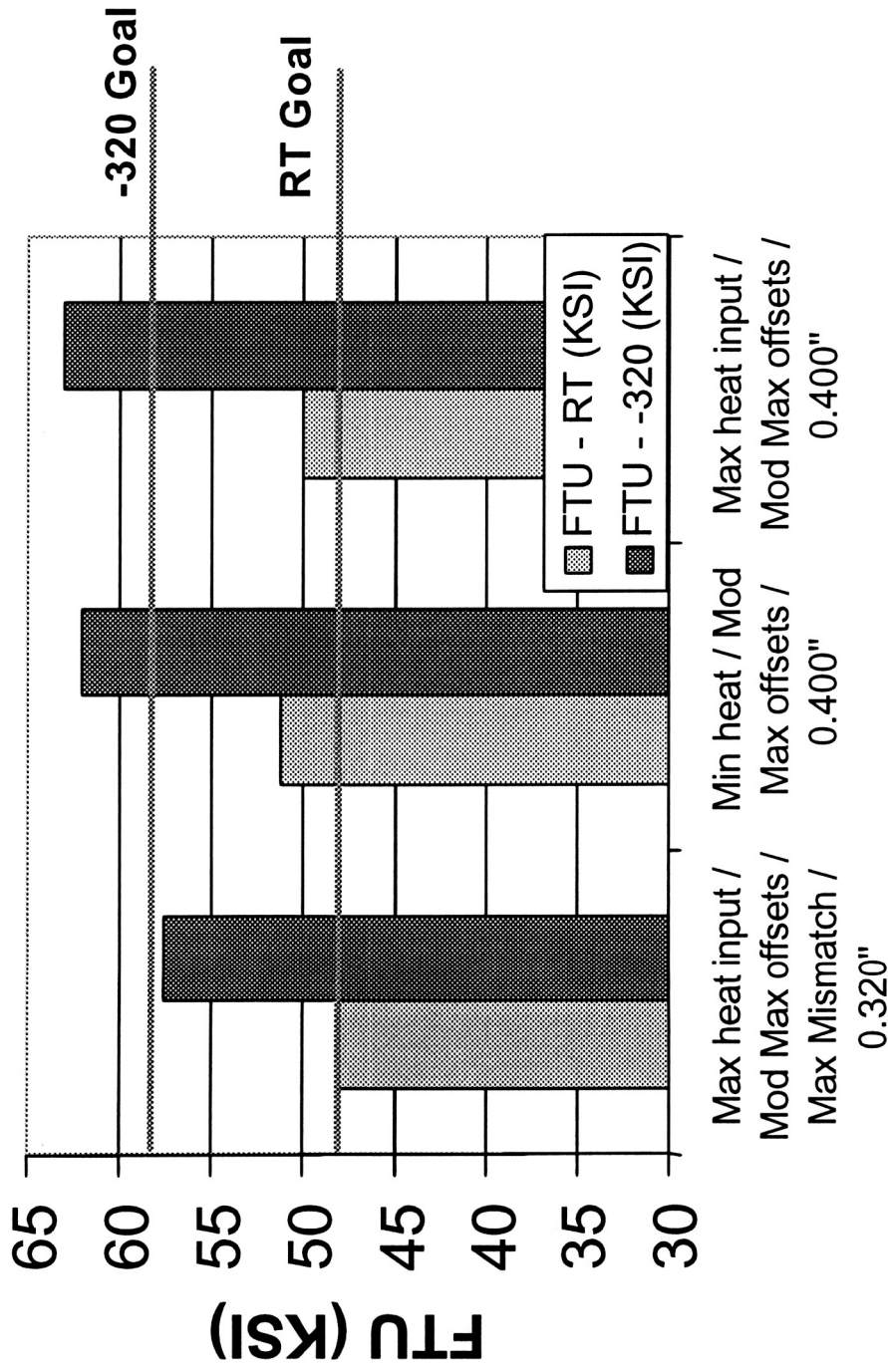
Al2219 to Al2219 Set-up Verification DOE



Weld Condition

Weld Process Development

Al2219 to Al2219 Set-up Verification DOE

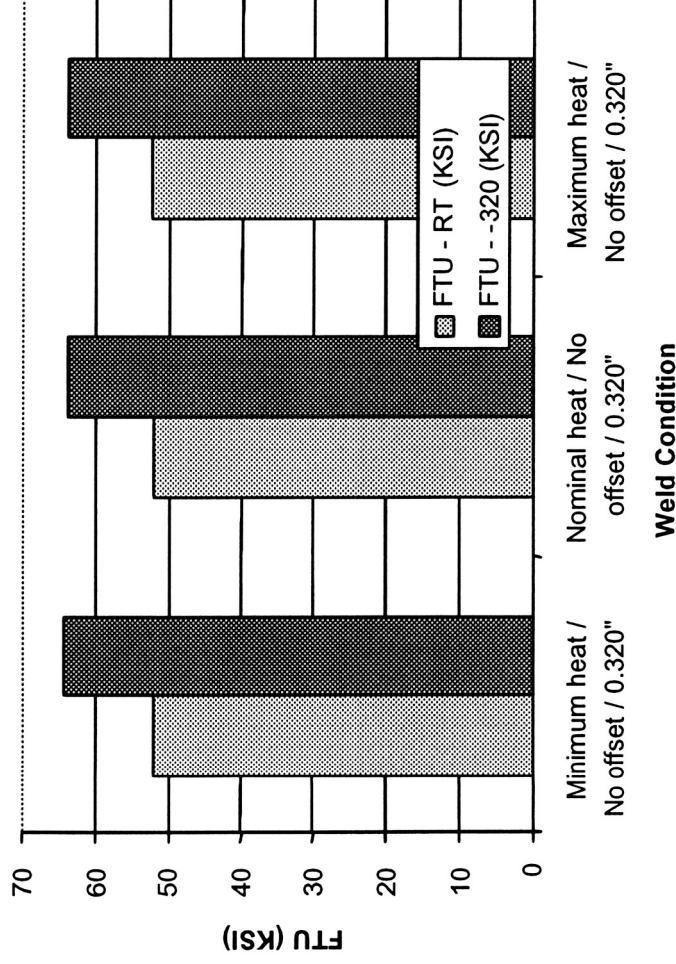


Weld Condition

Weld Process Development

AI2219 to AI2219 Tack / Weld Schedule Verification

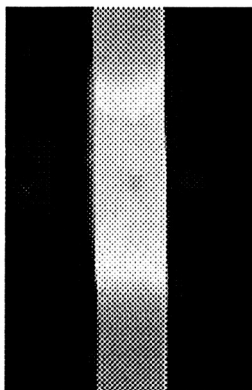
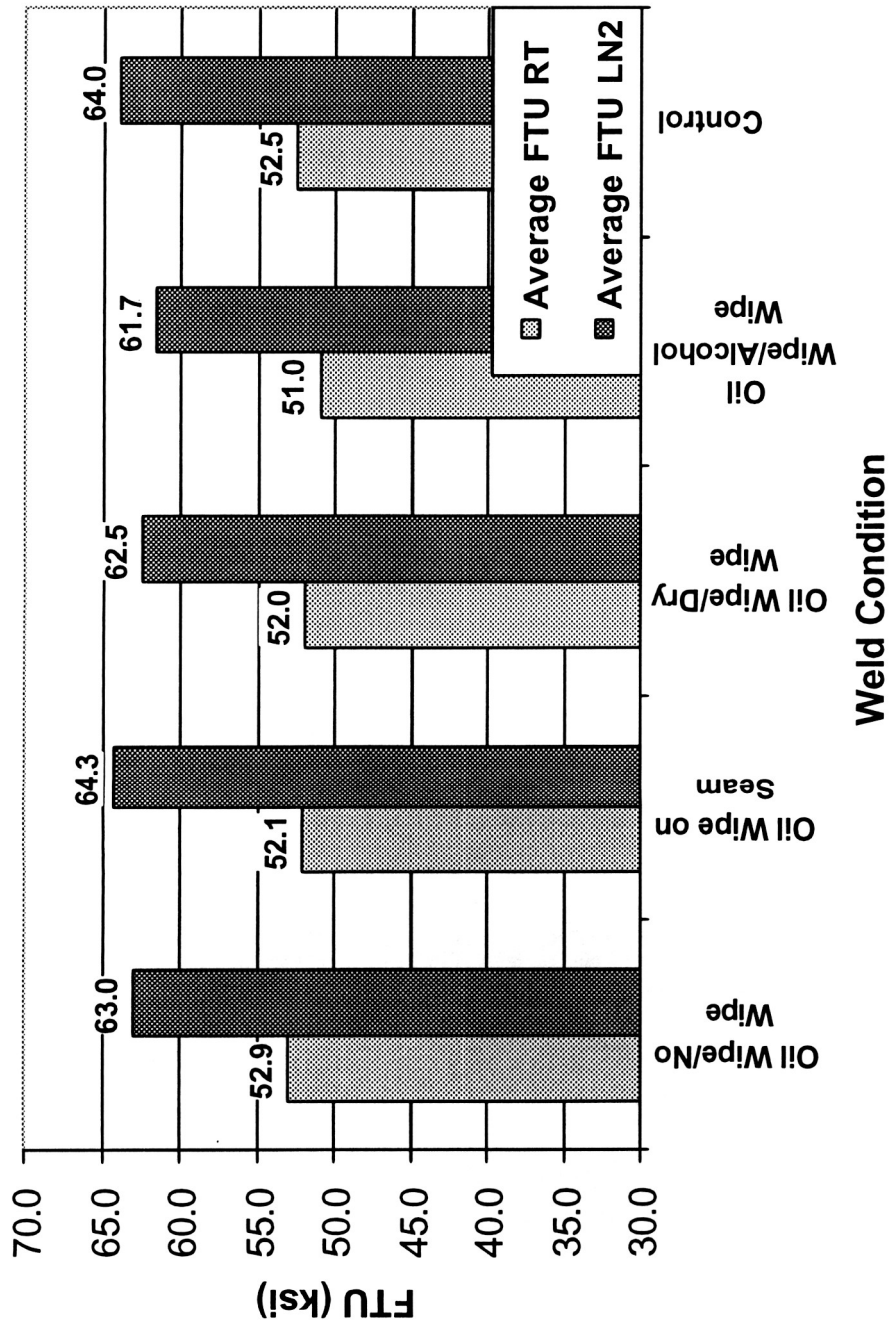
- Tack and self reacted welds without side restraints were conducted to evaluate the effects from the tack on the schedule.
 - 2 Weld Panels At Nominal Schedule
 - 1 Weld panel at Maximum Schedule
 - 1 Weld Panel A Minimum Schedule



All Panels Exceeded Room and -320 °F Strength Goals

Weld Process Development

Effects of Oil Contamination

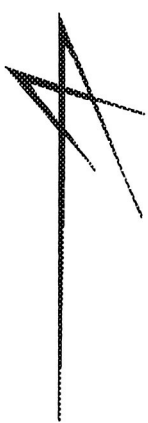


Oil Contaminated With No Cleaning

Rotation / Travel / Load
 250 rpm / 12 ipm / 4000 lbs

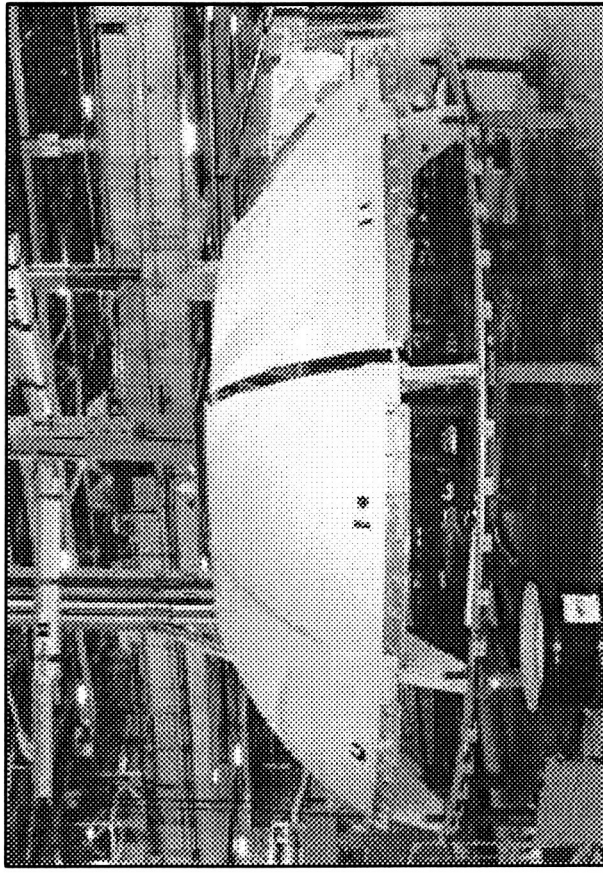
Oil contamination testing showed no significant decrease in mechanical properties

Weld Process Transfer

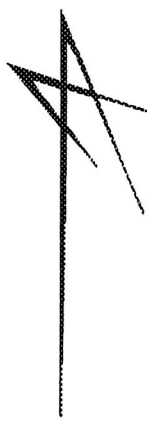


Approach

- **Modify an existing fusion weld 22 ft. dia. dome weld tool to accommodate the AdAPT weld head, induced loads from the FSW process and clamping requirements**
- **Ensure weld schedule transfer from test fixture to dome tooling using short and full length confidence panels. Considerations include:**
 - **Dynamic weld head attitude**
 - **Tacking procedure**
 - **Allowable fit-up tolerances**
 - **Start/stop tab procedure**



Weld Process Transfer

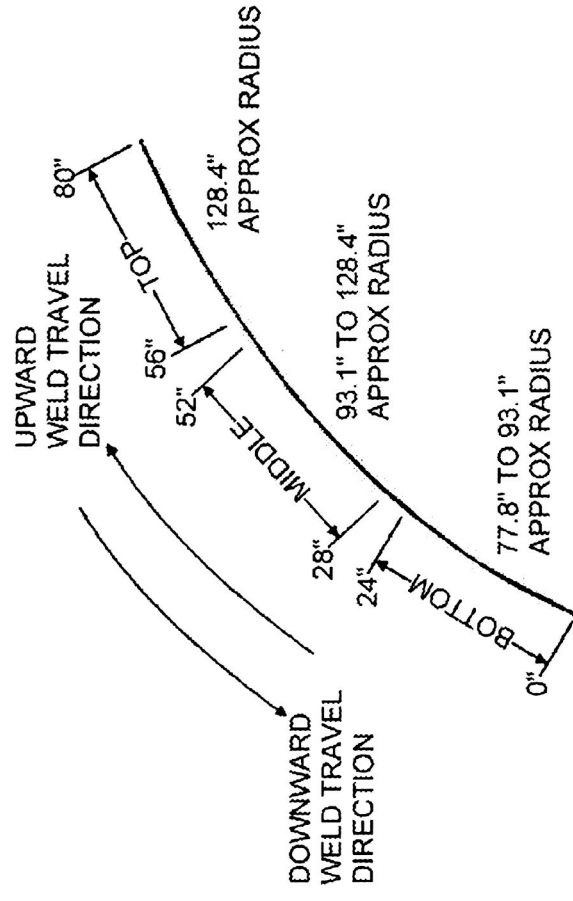


Perform weld process verification, using “Best” set of parameters as determined from Weld Process Development and geometrical variance

- Curved 24” panels at bottom, middle, and top positions in Gore-to-Gore tool
- Curved 24” panels at bottom and top positions to validate start / stop tab procedures
- Full length constant curvature confidence panels

Success Criteria

- Average room temperature $F_{tu} \sim 48$ ksi
- LN2 enhancement of 1.2
- Visual & Radiographic Inspection



Intermediate Hardware Fabrication

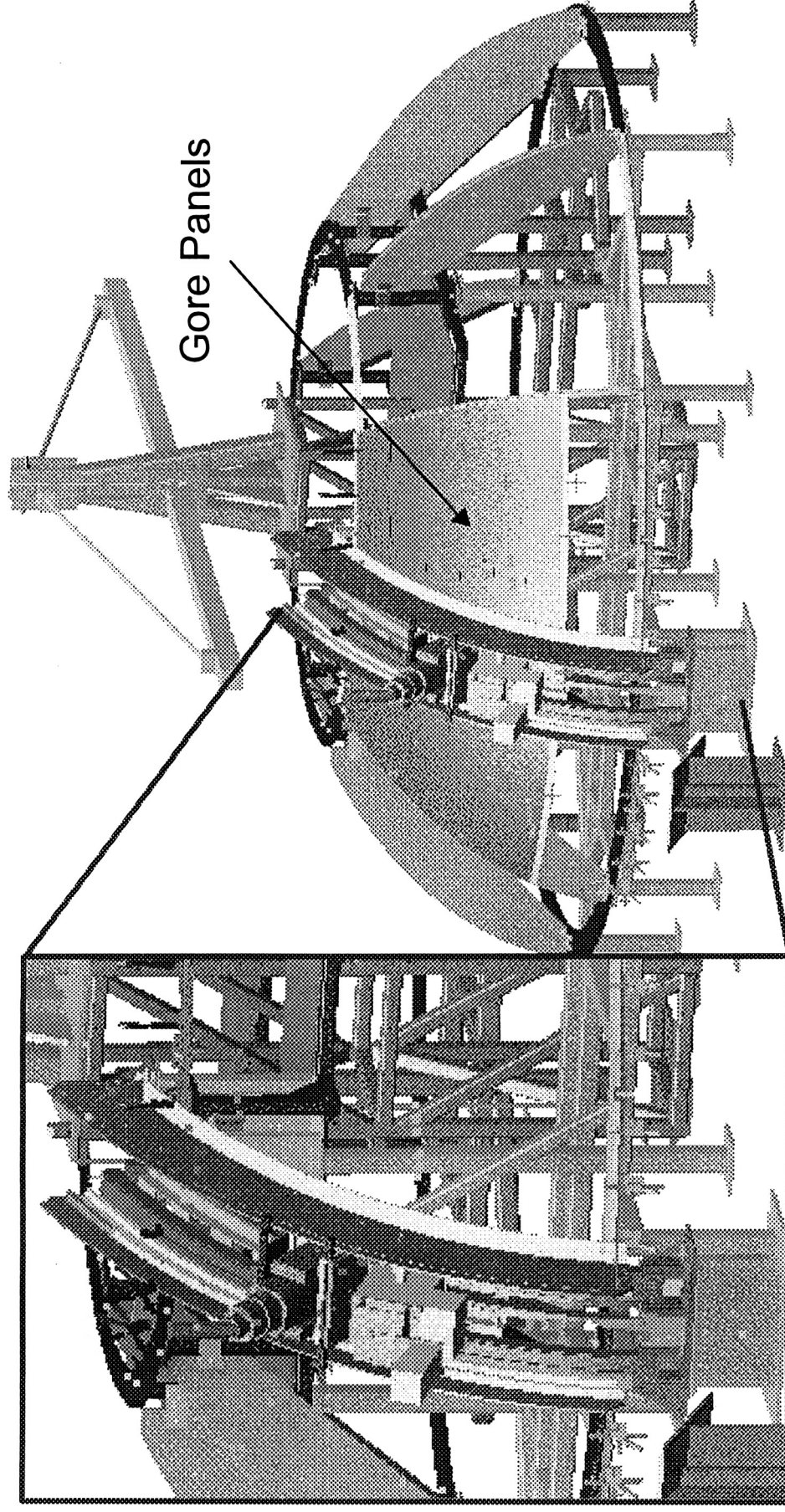


Tooling Modification

- Tool Requirements
 - Track and drive system to hold, position and drive AdAPT Weld Head
 - Signal interface to MTS Control System
 - Maintain Pin Tool angle normal ($\pm 0.25^\circ$) to part surface
 - Removable anvil (used for fixed pin tack welding)
 - Provide access for pin removal and backside shoulder at all travel positions
 - Part clamping at 100 pounds per linear inch (minimum)
- 24" Test Panels
- 84" Confidence Panels
- Intermediate scale Gore Panels
- Support for hydraulic manifold and hoses
- Provide camera for video recording of leading and trailing of weld

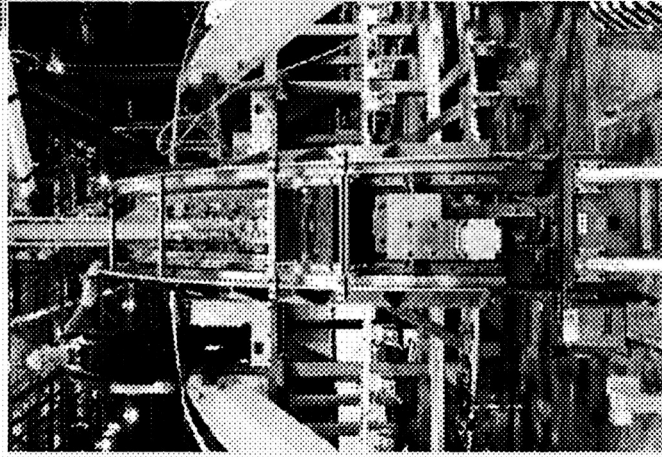
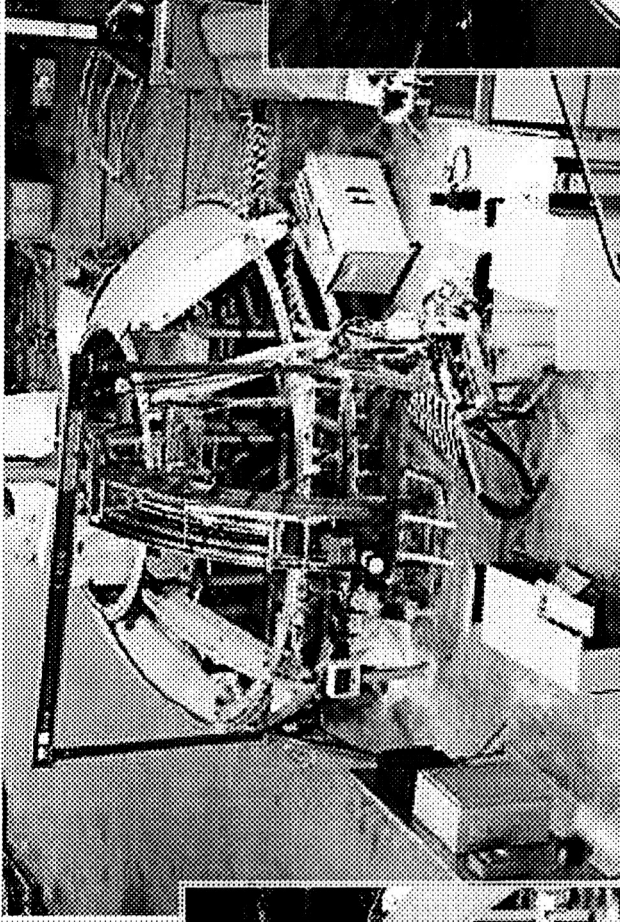
Intermediate Hardware Fabrication

Intermediate Scale Weld Tool Modification - Design



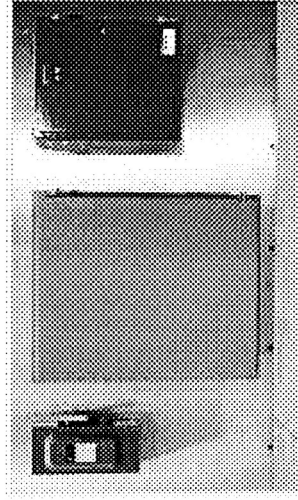
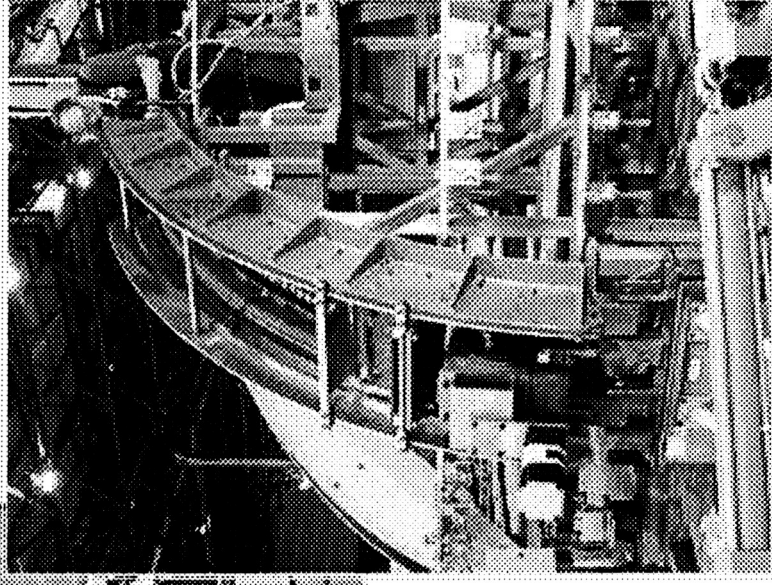
Intermediate Hardware Fabrication

Intermediate Scale Weld Tool Modification - Installation



Weld Track & Carriage

Weld Track & Carriage

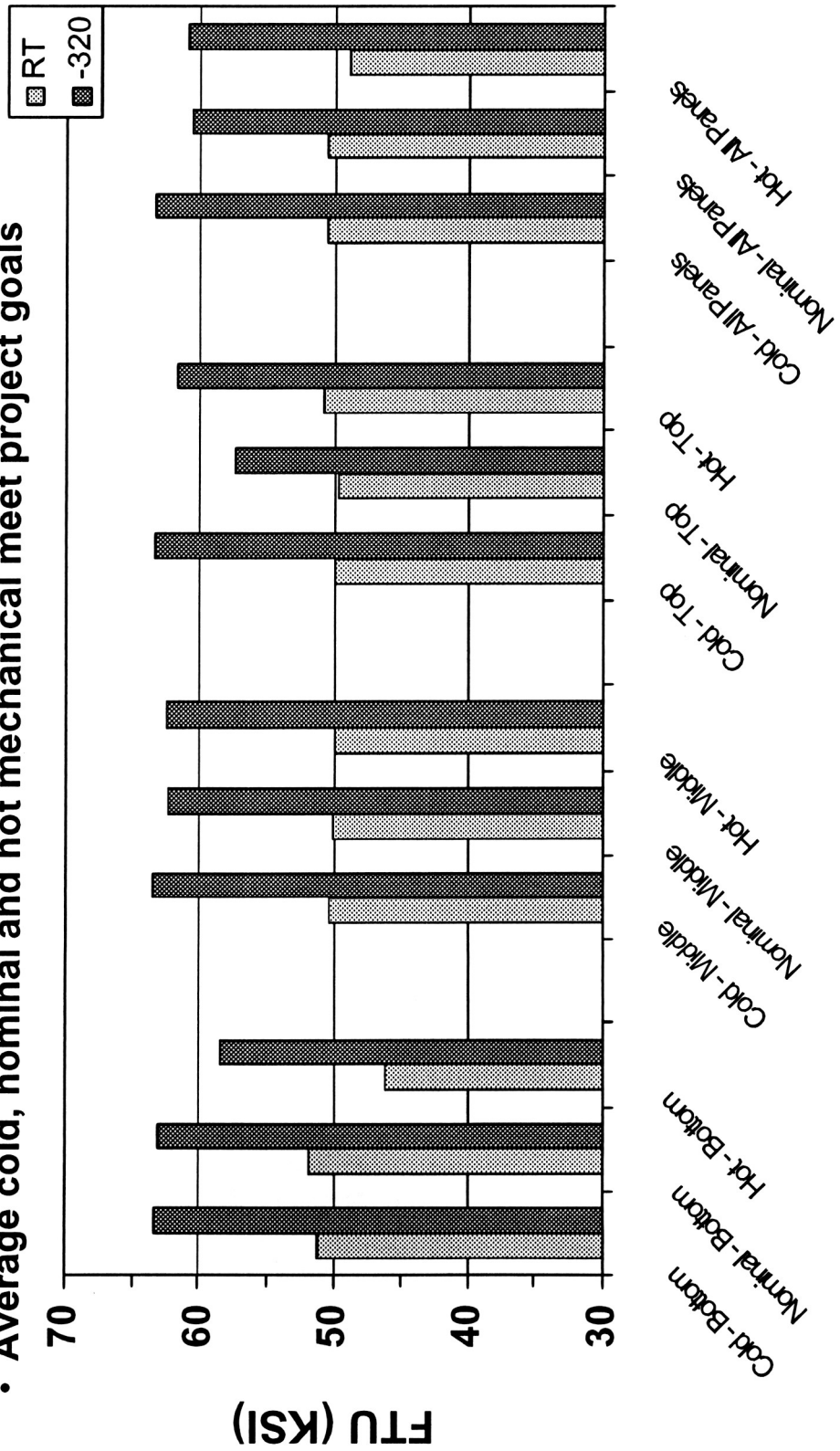


Electronic Enclosures & Disconnect

Weld Process Transfer

Weld schedule transfer from the PDF to the Gore-to Gore tool was successful

- Fixture was not specially designed to hold short panel - panels required a tack weld
- Average cold, nominal and hot mechanical meet project goals

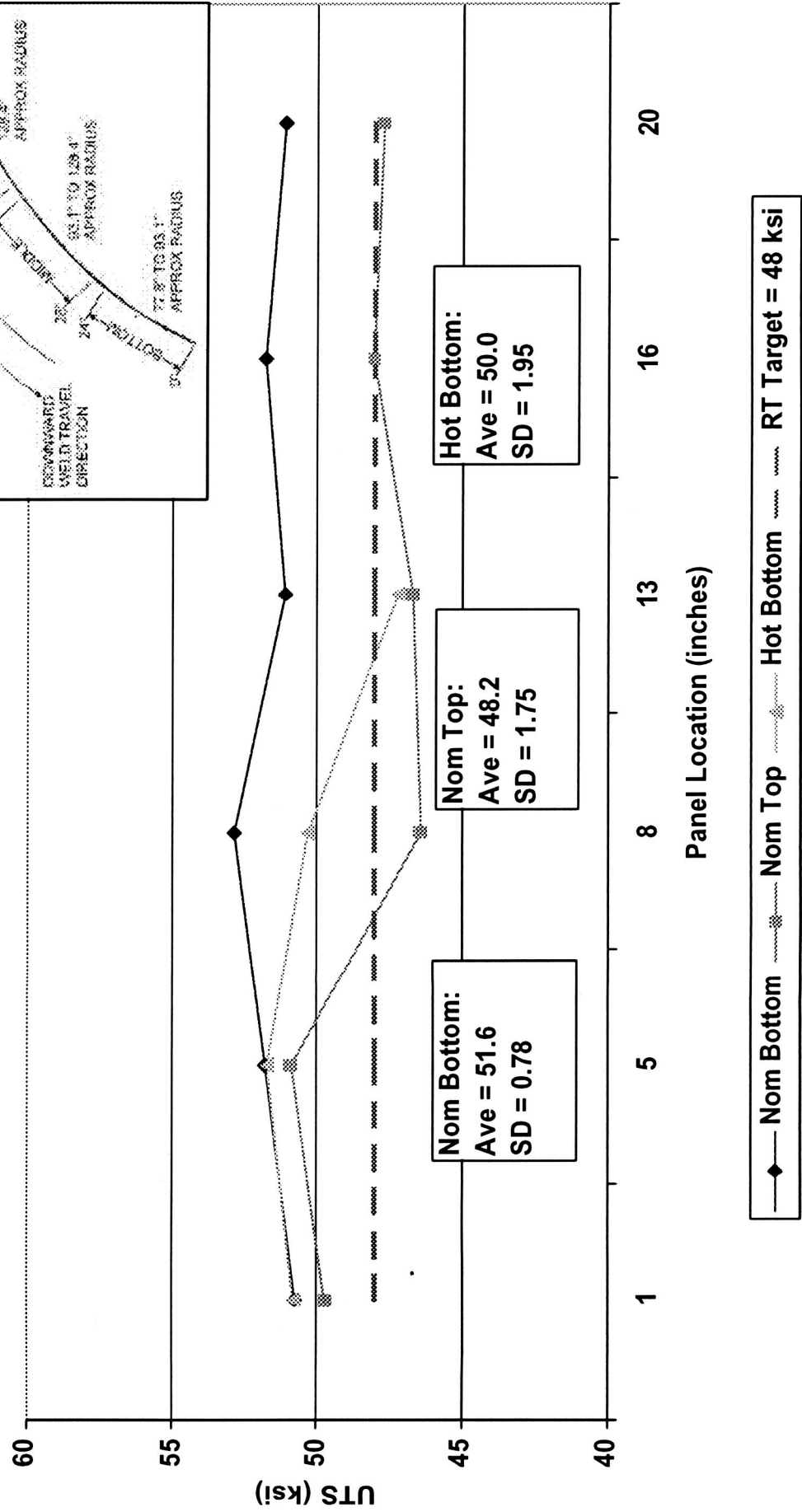


Weld Location

Weld Process Transfer

RT mechanical properties for the 24" panels

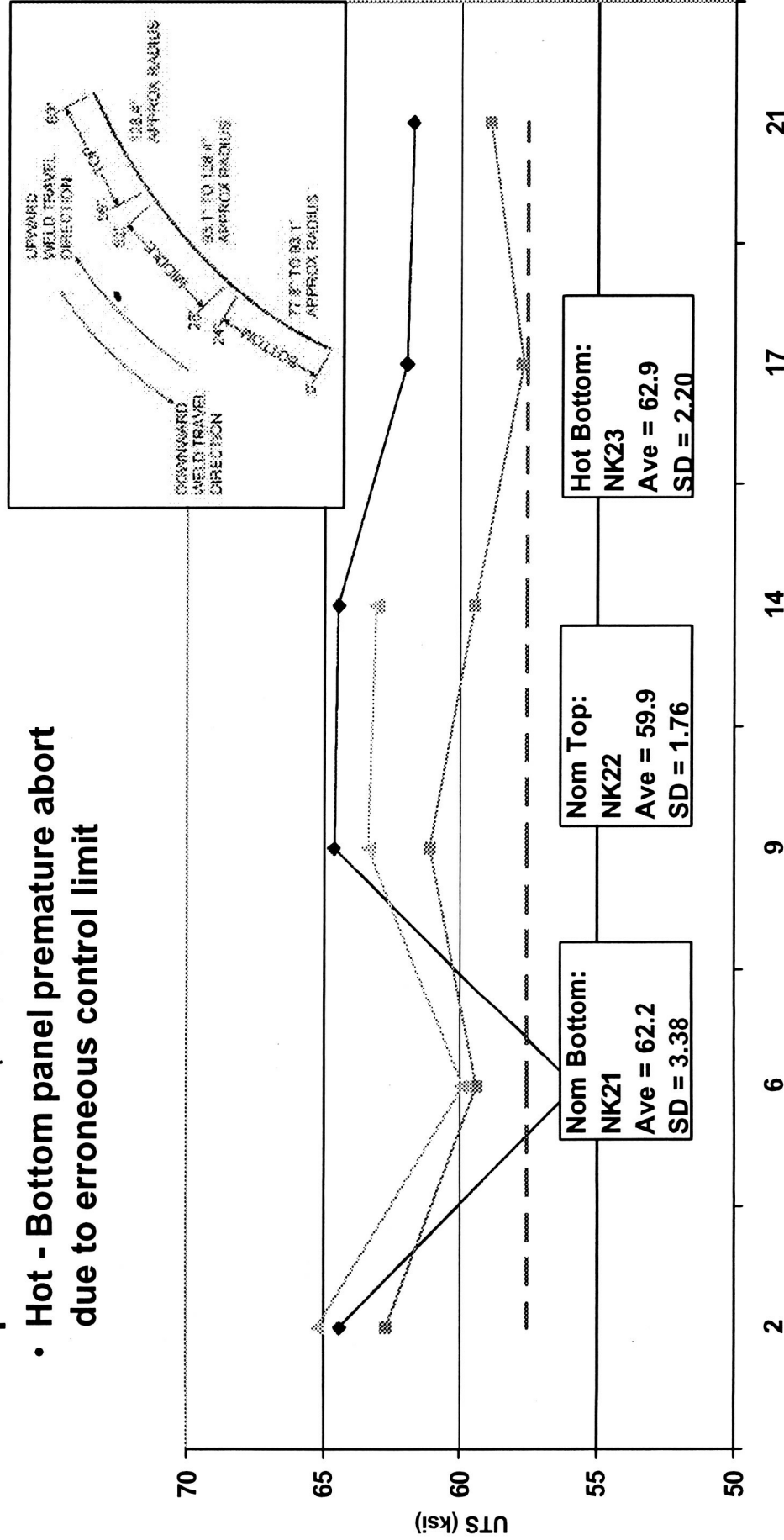
- Hot - Bottom panel premature abort due to erroneous control limit



Weld Process Transfer

LN2 mechanical properties for the 24" panel with weld tabs

- Hot - Bottom panel premature abort due to erroneous control limit

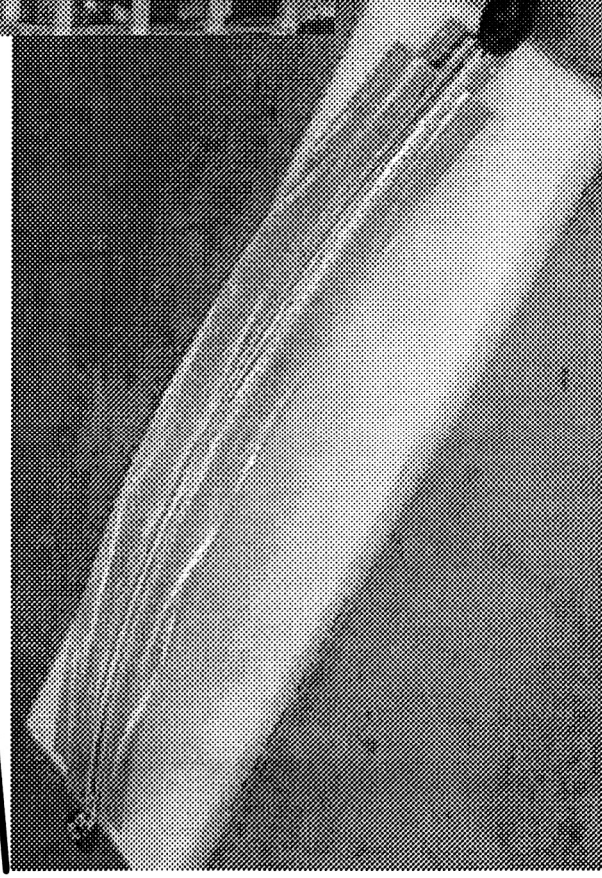
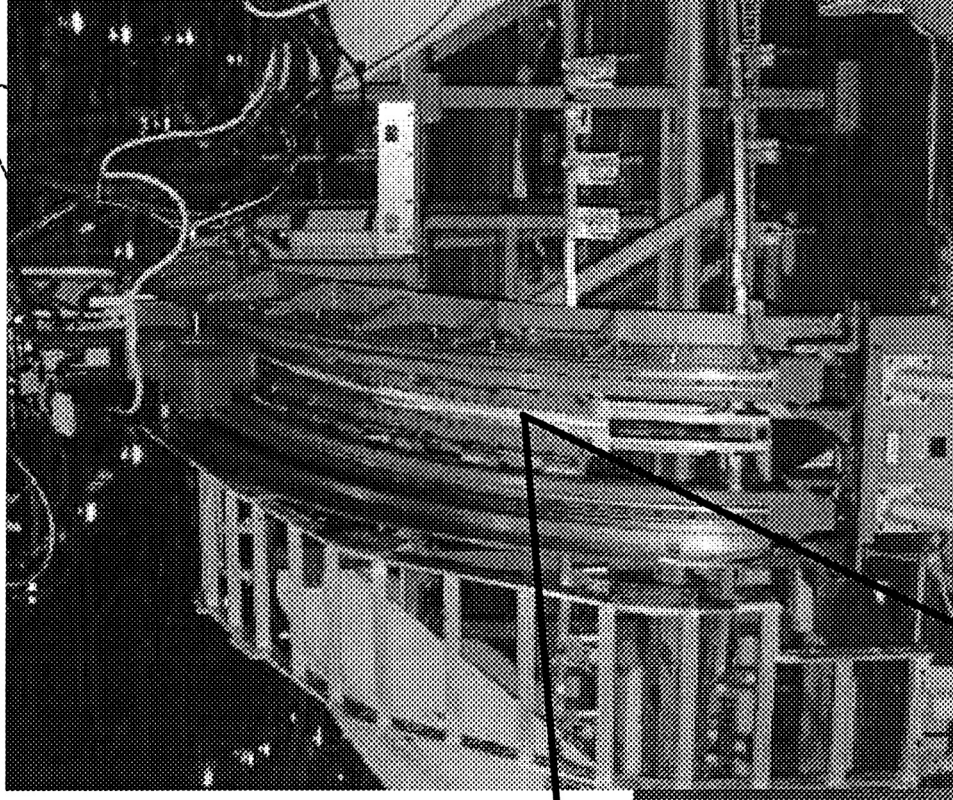


◆ Nom Bottom □ Nom Top × Hot Bottom RT Target = 57.6 ksi

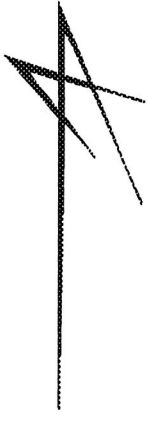
Intermediate Hardware Fabrication

84" full length confidence panels were successfully welded prior to welding the demonstration article

- Confidence panels were welded to validate full length welding ability with addition of start / stop tabs

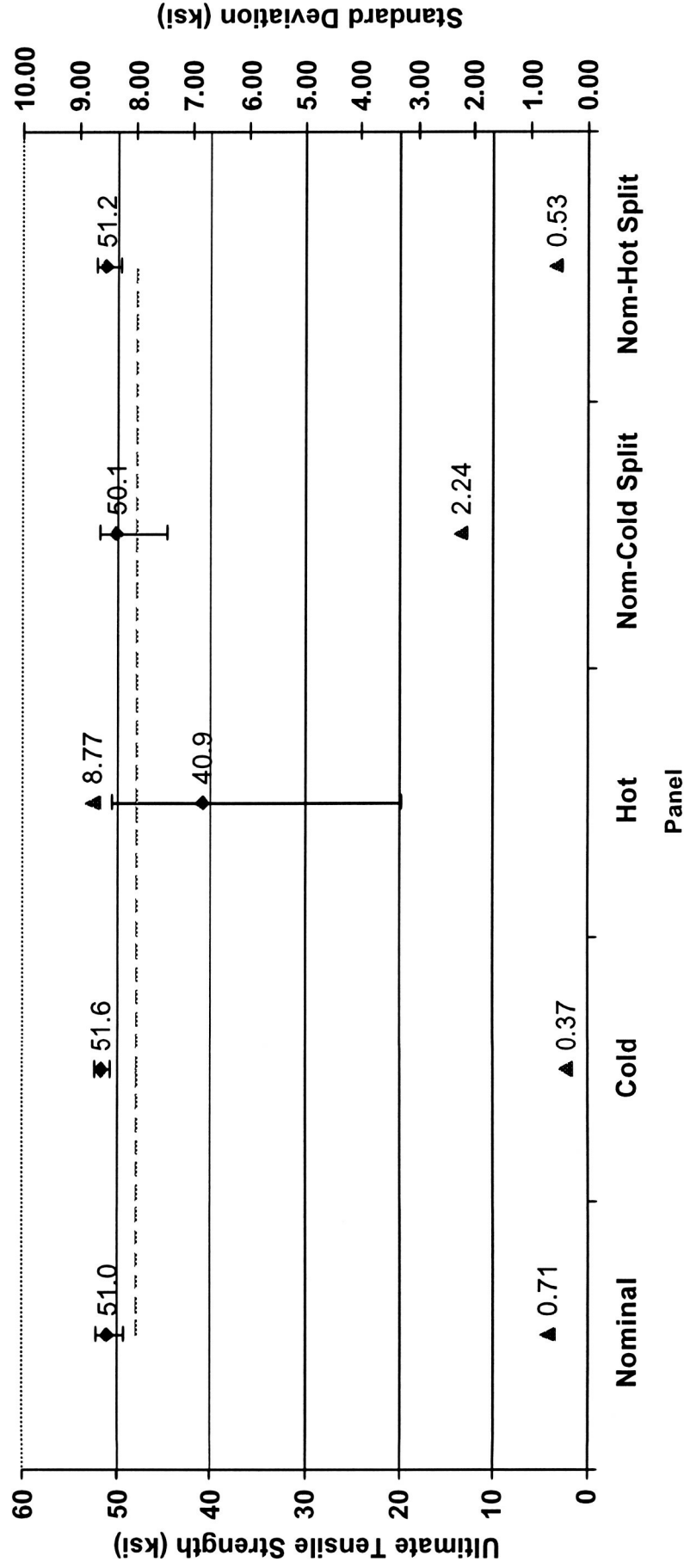


Weld Process Transfer



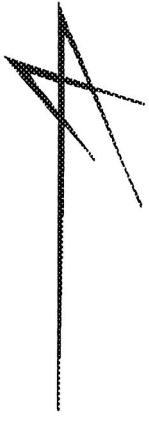
RT mechanical properties for the 84" panels

- Weld schedule transfer from the 24" to 84" panels was successful
- Hot panel did not meet goal due to poor seam alignment



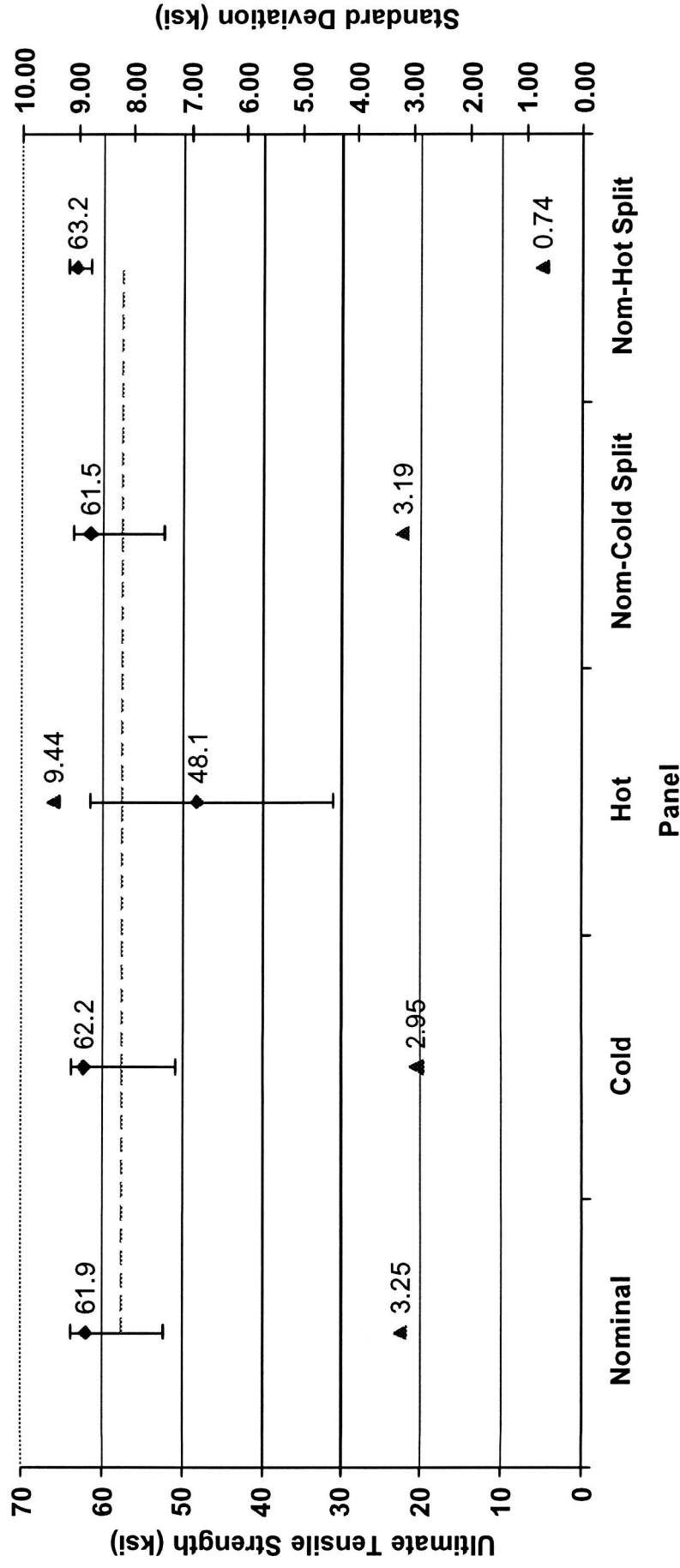
◆ Average UTS --- RT Goal = 48 ksi ▲ Std. Deviation

Weld Process Transfer



RT mechanical properties for the 84" panels

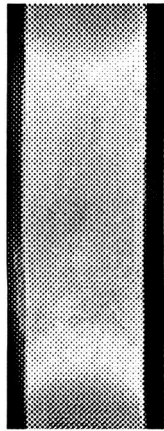
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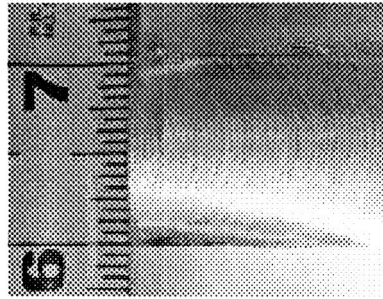
◆ Average UTS - - - - -320F Goal = 57.6 ksi ▲ Std. Deviation

Intermediate Hardware Demonstration

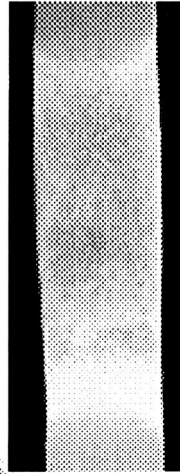
Confidence Panel Results



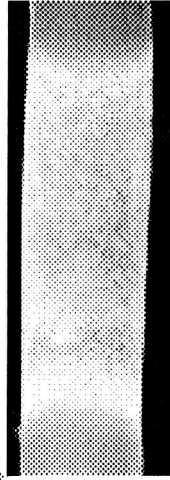
Development Macro



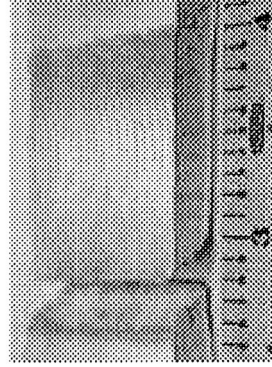
Typ. Crown Appearance



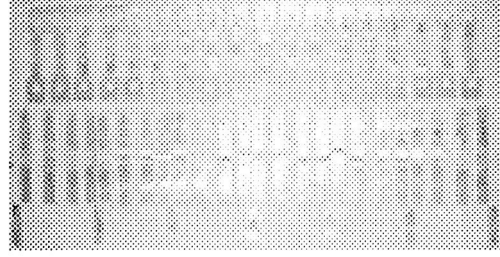
Confidence Macro: Weld Start



Confidence Macro: Mid-Weld



Typ. Tensile Fracture



Confidence Macro: End of Weld

0.320" Thick Al2219/Al2219 Welding (ksi):

	Fusion Ave Req	FSW Goal	FSW Ave	FSW Std Dev
Room Temp	40	48	51.2	0.53
-320°F	48	58	63.1	0.72

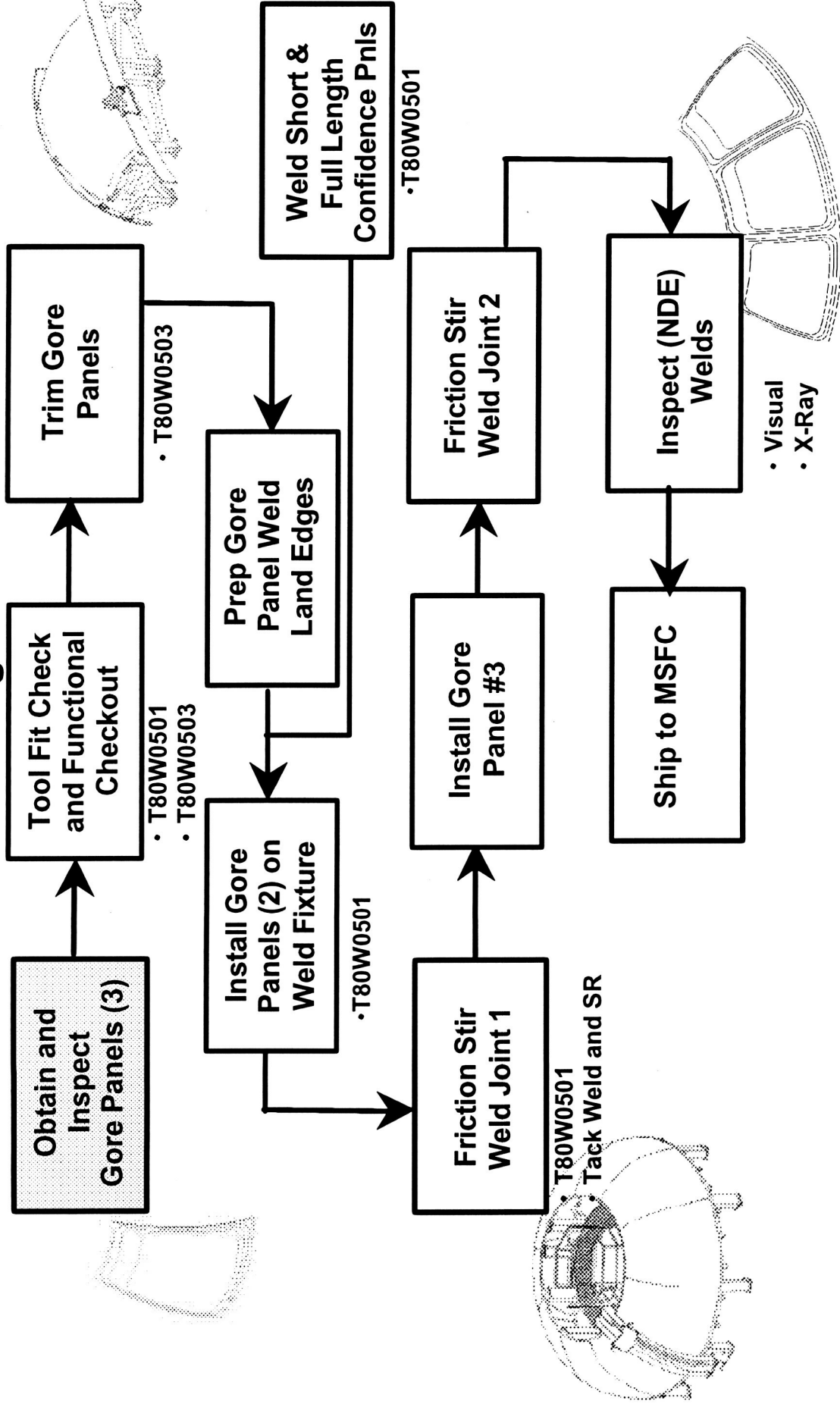
Per Conf. Panel

7xMs, 24xRTs, 18x-320s

- Seamless flat to complex curvature weld schedule transition
- Exceptionally consistent, high tensile results

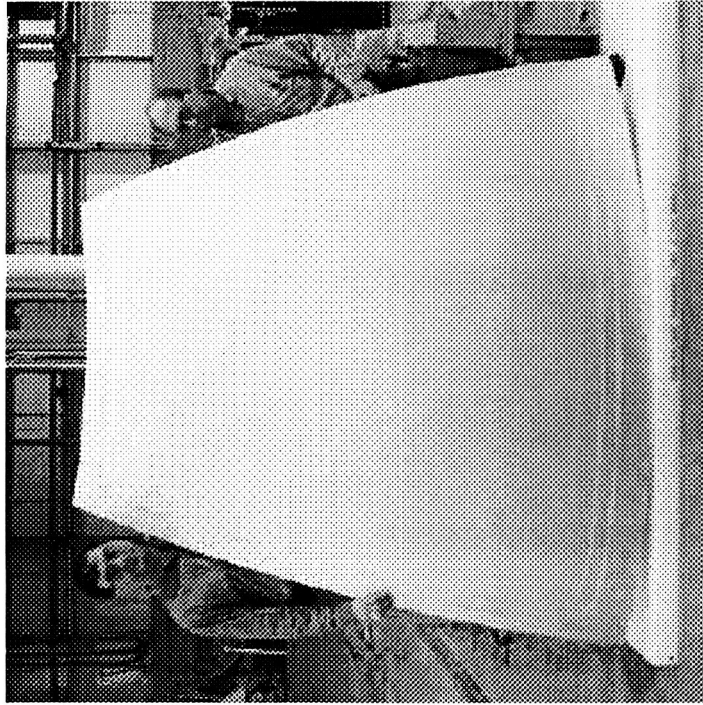
Intermediate Hardware Fabrication

Manufacturing Flow



Intermediate Hardware Fabrication

Intermediate Scale Gore Configuration

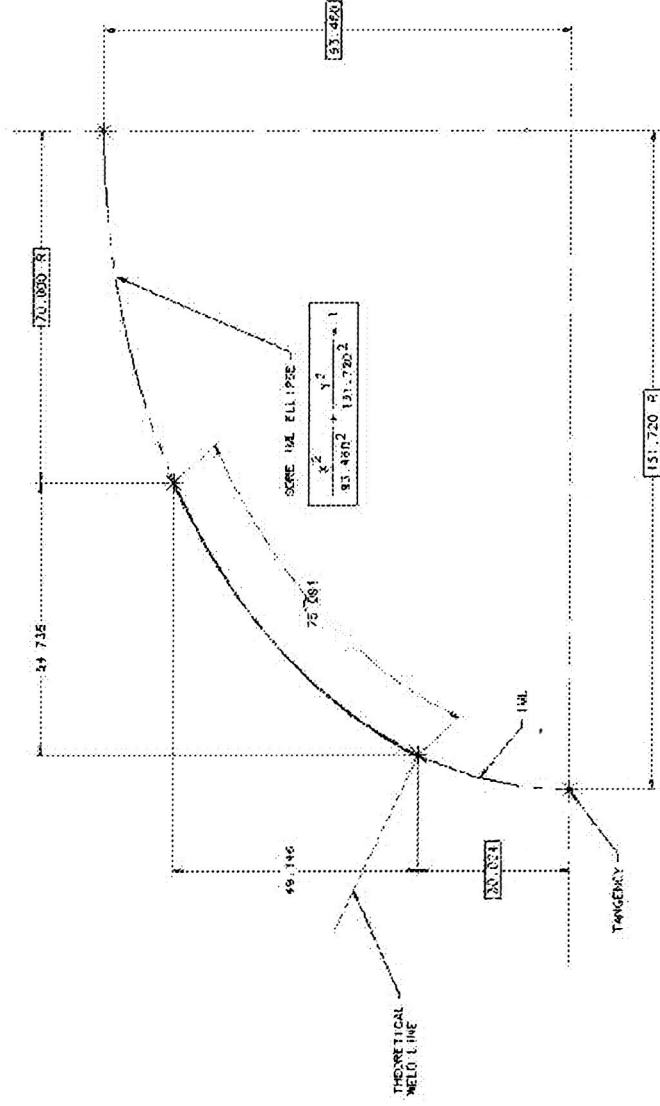
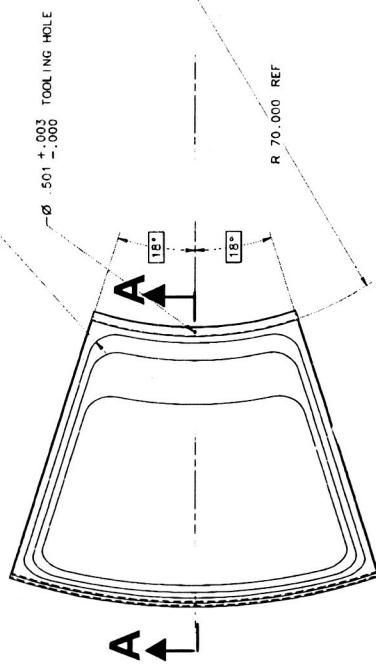


- Weld land thickness
– 0.320" constant

R 6.00 ±.00 TRUE TYP
12 PLACES NS & FS

Ø .501 ±.003 TOOLING HOLE

R 70.000 REF

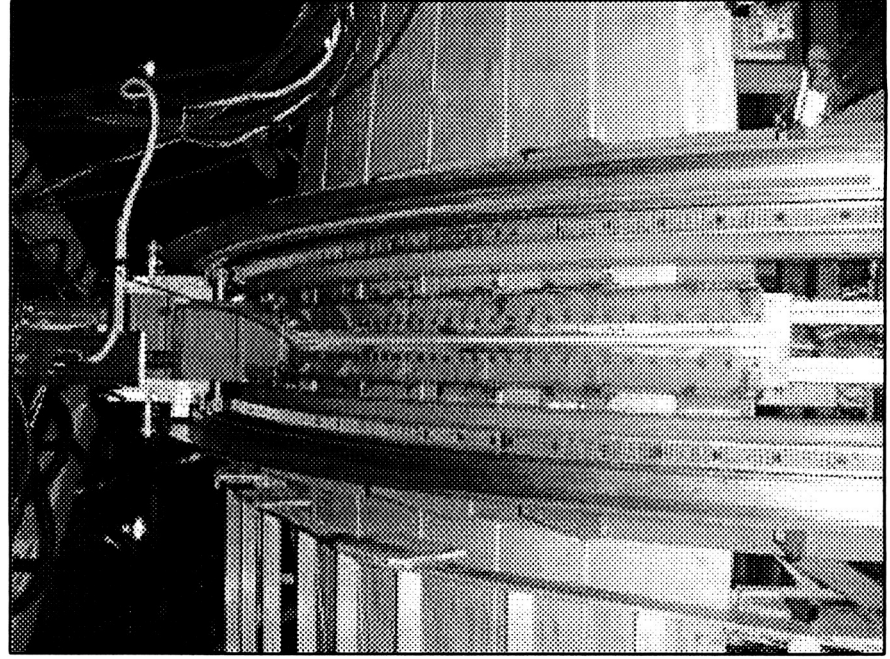


Section A-A

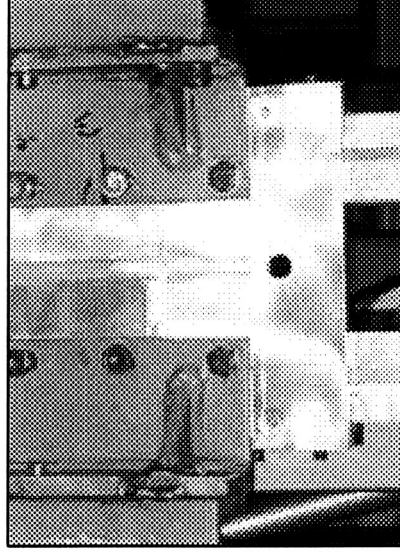
Intermediate Hardware Fabrication

Set up and welding of the intermediate gore-to-gore welds

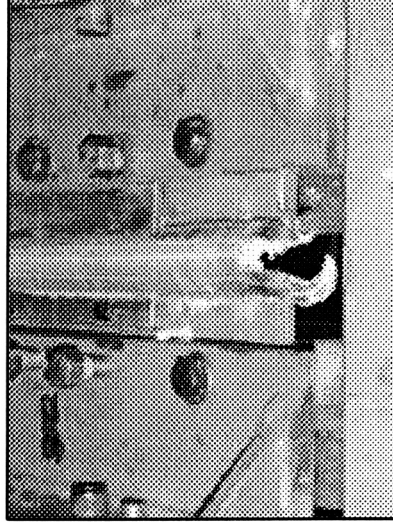
- Partial penetration fixed pin, continuous length tack weld
 - Completely consumed by the self-reacting weld
- Start and stop tabs for the weld initiation and tail-out, respectively



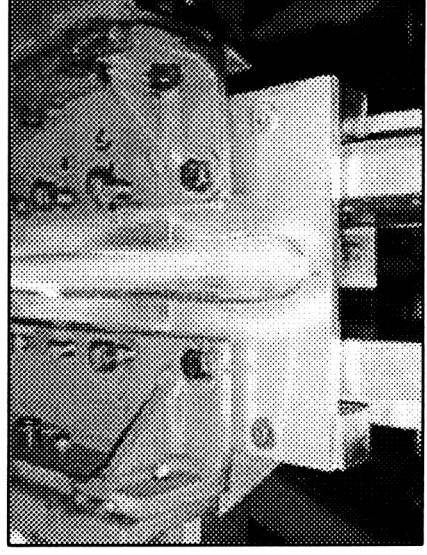
Gore panels during welding



Start tab after Tack weld

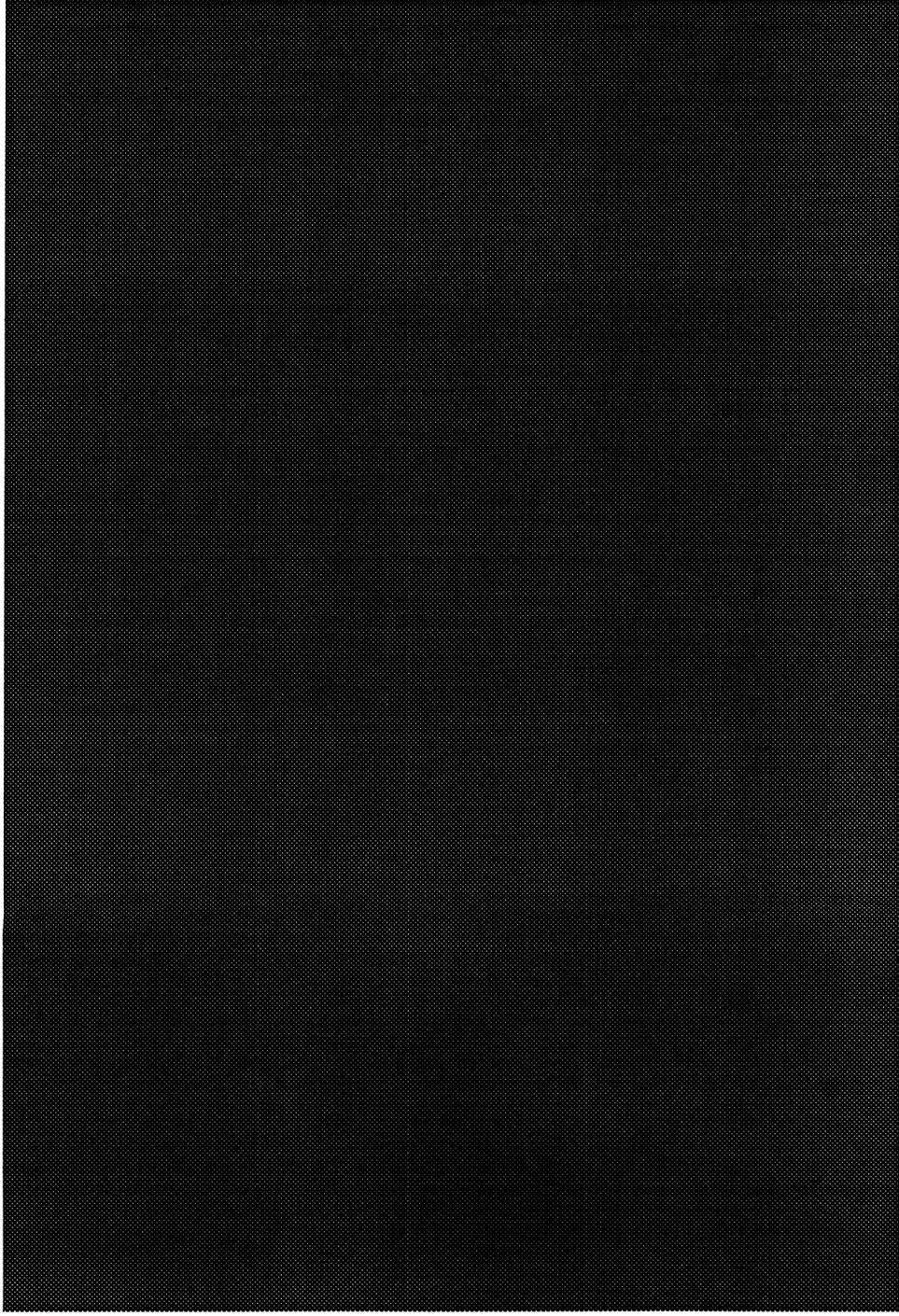


Run-out tab after SR-FSW



Start tab after SR-FSW

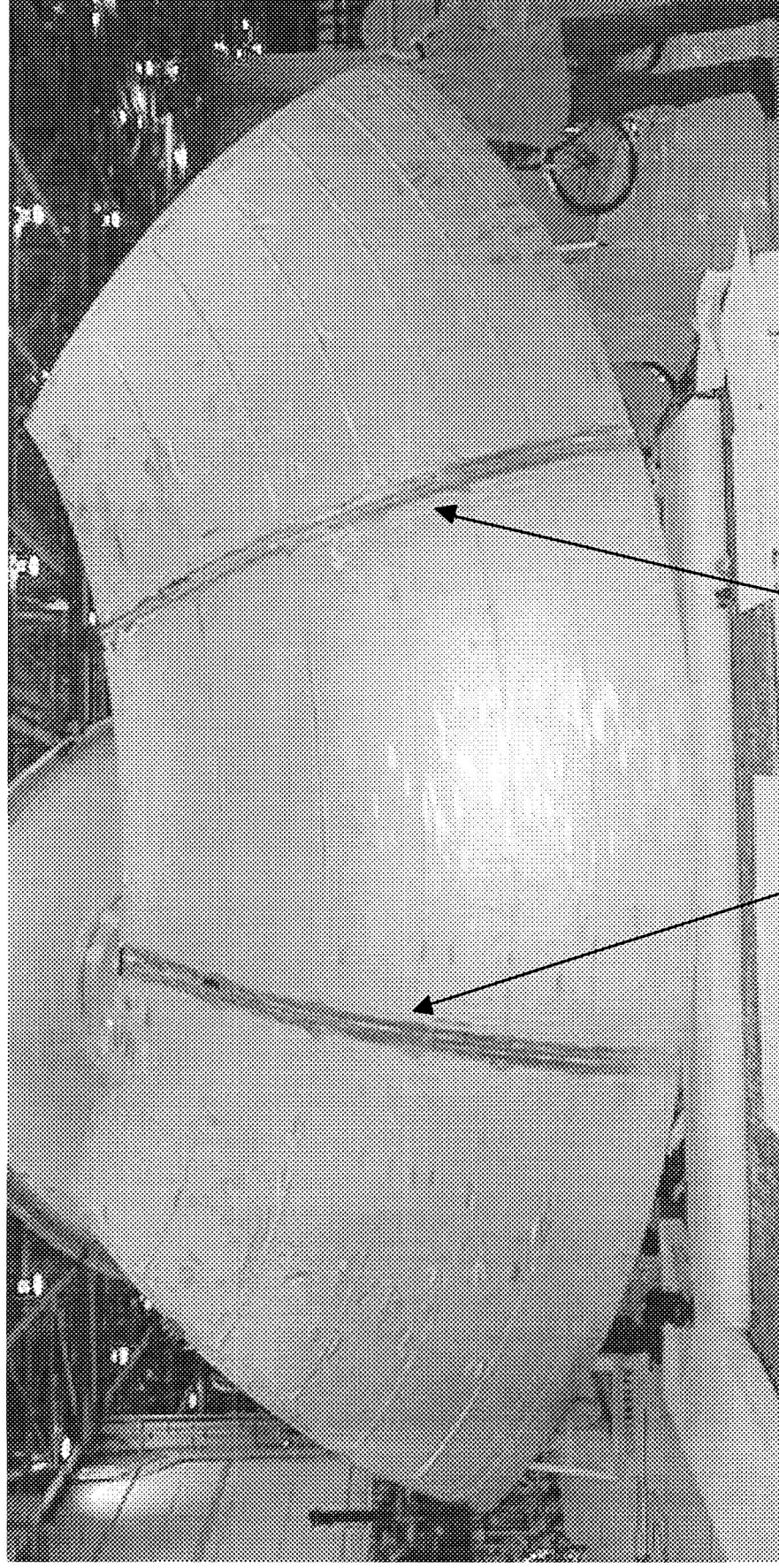
Intermediate Hardware Fabrication



Intermediate Hardware Fabrication

Success demonstration of an Al2219 self-reacting gore to gore weld

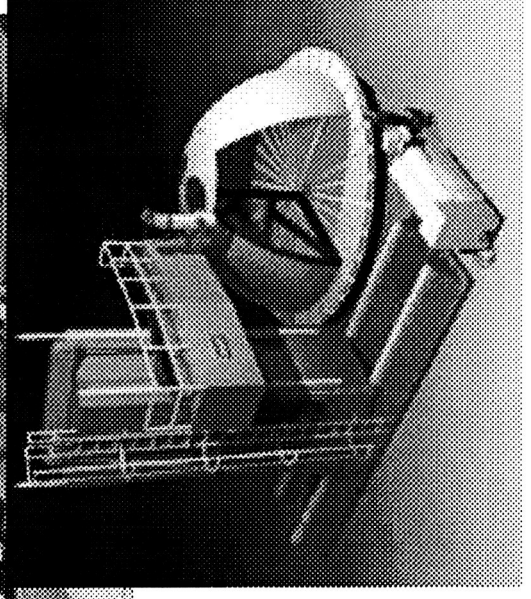
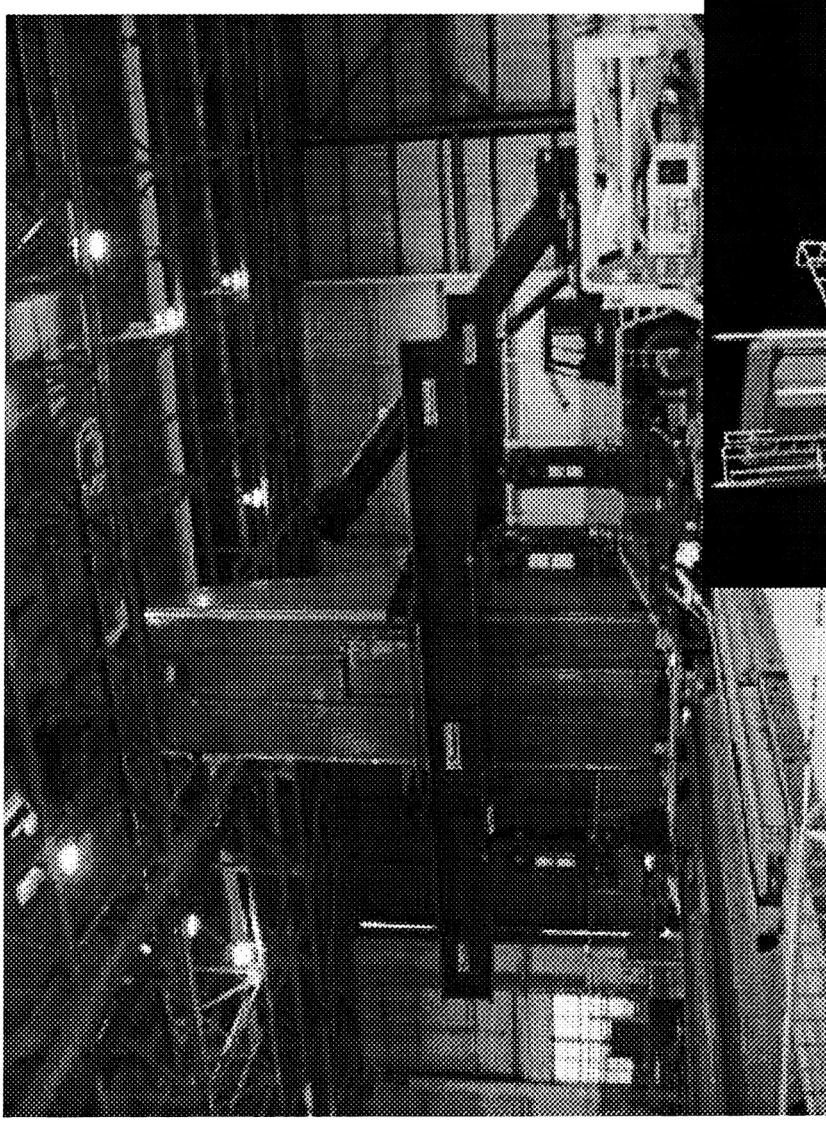
- 84 inch long - 0.320 inch constant thickness weld lands
- Slight chem-milled weld lands resulted in localized “flash”



The Next Step

The Universal Weld System (UWS) will be operational at the Michoud Assembly Facility in Sept. 2003

- Designed and fabricated by MTS Systems
- Enables fabrication of a External Tank size (27.5 ft dia.) domes and barrels
- Quarter Panel fabrication with a flexible tooling approach will be performed by 10/1/03



Summary

Lockheed Martin and the NASA have advanced the self-reacting friction stir weld technology for complex curvature aluminum alloys

- Successful weld process development for 0.320" Al 2219
- Successful transfer from the "lab" scale to the production scale tool
- Weld quality exceeds strength goals

The Universal Weld System enables development and implementation of large scale complex geometry hardware fabrication

- Al2195 tapered thickness gore-to-gore demonstration program planned for September 2003